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Title: Determinants of personal exposure to ozone in school children. Results from a panel study in Greece.

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Abstract

Background: In the wider framework of the RESPOZE (ReSPiratory effects of OZone Exposure in Greek children) panel study, we investigated possible determinants of O_3 exposure of school children, measured with personal passive samplers, in Athens and Thessaloniki, Greece.

Methods: Personal exposure to O_3 was measured for five weeks spread along the academic year 2013-14, in 186 school children in Athens and Thessaloniki, Greece. At the same time, at-school outdoor measurements were performed and ambient levels of 8-hour daily maximum O_3 from fixed sites were collected. We also collected information on lifestyle and housing characteristics through an extended general questionnaire (GQ) and each participant completed daily time activity diaries (TADs) during the study period.

Results: Mean outdoor concentrations were higher during the warmer months, in the suburbs of the cities and in Athens. Personal exposure concentrations were significantly lower compared to outdoor. Daily levels of at-school outdoor and ambient levels of O_3 from fixed sites were significant determinants of personal exposure to O_3. For a 10 $\mu g/m^3$ increase in at-school outdoor O_3 concentrations and PM_{10} measurements a 20.9% (95% CI: 13% , 28%) increase in personal exposure to O_3 was found. For a half an hour more spent in transportation an average increase of 7% (95% CI: 0.3% , 14.6%) in personal exposure to O_3 was observed. Among other possible determinants, time spent in transportation (TAD variable) and duration of open windows were the ones associated with personal O_3 exposure levels.

Conclusions: Our results support the use of outdoor and ambient measurements from fixed sites in epidemiological studies as a proxy of personal exposure to O_3, but this has to be calibrated taking into account personal measurements and time-activity patterns.

Keywords: Personal exposure, Time-activity diaries, Ozone, Panel study, Air pollution

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Introduction

Ozone (O_3) is one of the main components of the photochemical air pollution mixture. It is a highly reactive gas formed by the reaction with sunlight (photochemical reaction) of primary pollutants such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs) originating mainly from vehicle emissions but also from solvents and industry (WHO, 2014).

Investigation of the association between health outcomes and exposure to O_3 is often conducted by using routine measurements performed at outdoor fixed sites. Time series studies in Europe, the U.S. and Asia, have associated short term exposure to outdoor O_3 with adverse health effects (Bell et al., 2004; Choi et al., 2011; Darrow et al., 2014; Gryparis et al., 2004; Ito et al., 2005; Peel et al., 2005; Peng et al., 2013; Rodopoulou et al., 2014; Ghanbari Ghozikali et al, 2016; Miri et al, 2016), while panel studies (Liu et al., 2009; Nickmilder et al., 2007) that take into account repeated observations for the same individuals at specified periods of time have reached contradictory results. Cohort studies investigating the effects of long-term exposures (Lipfert et al., 2006; Krewski et al., 2009; Jerrett et al., 2009; Smith KR et al., 2009; Tzivian, 2011; Zanobetti & Schwartz, 2011) also provided inconsistent results.

Several air quality guidelines and standards are currently in application to protect the population from harmful air pollution effects following short term exposure. The World Health Organisation (WHO) has established a guideline value of 100μg/m^3 for the daily maximum 8-hours average ozone concentrations. . This recommended limit was reduced from the previous level of 120 μg/m^3, based on conclusive associations between lower O_3 concentrations and daily mortality (WHO, 2014). The most recent National Ambient Air Quality Standard~~s~~ (NAAQS) of the US Environmental Protection Agency (EPA) for O_3 was revised downwards to 0.070 ppm (140 μg/m^3)

for 8-hour exposure (EPA, 2015). The current European Union (EU) directive for O_3 defined a health protection threshold of 110 μg/m^3 for 8-hour mean concentrations (E.C. Ozone Directive, 2016).

Ozone concentrations measured at fixed sites have been used as a proxy for personal exposure (Liu et al., 2009; Nickmilder et al., 2007; Sienra-Monge et al., 2004). Although those are hypothesized to be collected and thus to reflect the average population exposure, they lack information on their quantitative association with personal exposure, the range of individual exposures and the relative contribution of factors, such as housing characteristics, behavioral aspects and time activity patterns.

Personal exposure assessment of O_3 has become feasible due to passive monitors that are small and light weighted (Koutrakis et al., 1993). Studies have been carried out using passive personal O_3 devices to monitor personal exposure of both children and adults for periods up to one week each time over the study periods (Geyh et al., 1999; Lee et al., 2004; Liu et al., 1993; Ramírez-Aguilar et al., 2008). To our knowledge, similar studies have not been conducted in the Mediterranean area, even though it is considered to be at highest O_3 risk in Europe due to precursor pollutant emissions and climate. Over the time period 2000-2010, Sicard et al. (2013) have demonstrated that O_3 concentrations are still increasing in Mediterranean cities, making ozone exposure a potential major public health concern in urban areas.

In this paper, we investigate possible determinants of personal exposure assessment of O_3, using individually carried passive samplers, during 5 weeks, in a representative sample of students aged 10-11 years in the two major cities of Greece, Athens (state capital) and Thessaloniki (second largest city and one of the main ports in the Mediterranean), performed in the framework of the panel study entitled ReSPiratory effects of OZone Exposure in Greek children (RESPOZE).

Methods and Data

Study design

In the RESPOZE study, personal exposure to O_3, using passive samplers, of 186 school children was measured in Athens and Thessaloniki, Greece. Measurements were performed during a total of five weeks in Athens and four weeks in Thessaloniki per student: two weeks in Athens and one in Thessaloniki were in the fall (October-December), one in the winter (February) and the final two weeks in the spring and early summer (April-June) for both cities (calendar weeks in the two cities were close but did not coincide in order to optimize the use of the instruments) . The field work took place during the academic year 2013-14. Information on daily habits and activities was collected from two sources and on different time scales: 1. from a general questionnaire (GQ) with questions on lifestyle and housing characteristics, and 2. through a daily time activity and symptoms diary (TAD).

All children in the study were 10-11 years old, attending the 5th grade of public elementary schools. Informed consent was signed from the parents of children willing to participate prior to the initiation of the study. The study design was approved by the Ethics Committee of the University of Athens and the Ministry of Education.

Sampling

We aimed for a sample of 100 students from Athens and 100 from Thessaloniki attending public schools. Students attending public schools are required to live in a radius of about 500m around the school. 60% of the sample was drawn from areas characterized by high O_3 concentrations (typically city suburbs) and 40% from areas with low O_3 (the city centers where ozone concentrations are lower, due to scavenging in the presence of primary pollutants), based on the school location. We sampled schools placed near a fixed monitoring site (within 2 km) in order to collect data on regulated pollutants to enable comparisons between personal exposure and fixed site measurements. We sampled 21 schools in total in Athens and 13 in Thessaloniki and our final sample consisted of 97 children in Athens and 89 in Thessaloniki. In general, the response rate of the children varied between schools and the number sampled from each school was from 1 to 19 students. More details on the sampling procedure can be found in Samoli et al. (2016)

Personal & At-School Outdoor O_3 measurements

Personal and at-school outdoor ozone measurements, resulting in weekly O_3 average concentrations, were made using the Ogawa passive ozone sampler (Ogawa & Co. USA Inc., Pompano Beach, FL), which is based on the nitrite-coated filter method (Koutrakis et al., 1993). Field blanks were collected as part of the quality assurance and control protocol. The method's limit of detection was calculated at 1.98 μg m^{-3} as three times the standard deviation of blanks. The precision was estimated by duplicate measurements, resulting in a coefficient of variation of 4.6%. The degree of agreement between passive O_3 measurements and regulatory monitoring was assessed by collocated 7-day outdoor measurements with a reference UV photometric instrument, at a site of the air quality monitoring network in Athens. Results of the comparison indicated good correlation between passive and reference methods (r^2=0.9). More details on the exposure assessment campaign can be found in Grivas et al.

Samplers were given to all students in Athens and Thessaloniki. A team of three field workers visited students at their schools twice for each field work week on the same weekday. At the beginning of the study week (first visit) O_3 personal samplers were distributed and were collected on the same day of the next week (second visit). The children were instructed to wear the personal O_3 samplers continuously at chest level for the 7-days over the study period of the 5 weeks. They were instructed to clip the sampler directly to outer clothing, wear the sampler continuously, except when sleeping, bathing, or engaged in an intense athletic activity, for which wearing the sampler was not allowed. During these times the samplers were placed nearby, on a surface elevated at breathing height. Approximately 85% of total personal samples were successfully collected and analyzed. Failed measurements were mainly due to children misplacing, damaging or incorrectly exposing the sampler.

In addition to the personal samplers carried by the children, for the respective 7-day measurement periods, at-school outdoor ozone measurements were made. Outdoor samplers were located on the roofs or at a high spot in the garden of 20 (out of 34) participating schools. Samplers were placed at a distance of at least 2m from the ground and were sheltered from weather elements using a PVC protective cap. Outdoor sampling locations were selected as to not be directly impacted by traffic. After completion of sampling, filters were extracted by ultrapure grade water and analyzed for nitrate ions using ion chromatography. Derived solute nitrate concentrations were blank corrected and converted to ambient ozone concentrations using data on sampling duration and rate. Samples with concentrations below the detection limit were assigned half the detection limit value.

As a result, for each participating child and over the complete study period, a dataset of 4 to 5 observations of a 7-day average personal and at-school outdoor O_3 concentration was calculated.

Data from the fixed site monitoring network

For both study areas and for the entire duration of the study period, ambient 8-hour daily maximum O_3 and daily PM_{10} data from the fixed site monitoring networks, operated by the Ministry of Environment & Energy (www.ypeka.gr), were collected. More specifically we obtained data from network monitors that were within 2km at the most to the sampled schools. In Athens, data were used from 6 nearby stations, of which 2 are placed in the low O_3 concentration areas and 4 placed in the high O_3 concentration areas. In Thessaloniki data were used from 3 nearby stations, one in the low O_3 concentration and 2 placed in the high O_3 concentration areas. For each child a weekly average ambient O_3 and PM_{10} concentration was calculated using data from the nearest station to the child's school and corresponding to the exact 7-days the child participated in the study.

General Questionnaire

Trained interviewers visited the families of the children and administered an extensive questionnaire before the beginning of the field work. Information was collected on demographic and socio-economic variables e.g. age (yrs), sex, father's education (yrs); life-style and residential characteristics e.g. in house cigarette smoking (yes/no), installed air-condition (yes/no), open windows (hours/day); lifestyle characteristics e.g. way of transport to school (on foot, car/bus, motorcycle, bike), and finally information on medical and residential history.

Time Activity Diary (TAD)

Information on daily activities that can be related to O_3 personal exposure was collected through TADs for each day during the study period. The TADs were distributed during the first school visit of every study week, when the participant was given a TAD and was instructed to record (self-completed) their daily activities in 15-min intervals across a 24-hr time period structured diary form. Responses were pre-coded into four categories: "at home", "outdoors" for locations such as parks or playgrounds, "in transportation" and "indoors other than at home" for locations such as the school, or other indoor locations visited for activities or social reasons (Figure 1). Using the TAD data we calculated for each child the time (in hours) spent daily at home, outdoors, in transportation and in other indoor~~s~~ spaces and consequently, we calculated the corresponding weekly average of time spent in each type of location, for each of the 5 study weeks. Additionally, each TAD included questions on occurrence of daily symptoms and school absenteeism; self-performed rheometer peak expiratory flow (PEF) measurements; and information of any incident regarding the use of the ozone personal sampler. TADs were inspected for data quality, proper completion or incorrect recordings when collected by the field workers during the second school visit at the end of each study week.

Statistical methods

The main objective of this analysis is to investigate which variables affect personal ozone exposure as measured by the individual passive samplers. Therefore in our analysis personal ozone measurements were the dependent variable. As potential determinants of the personal ozone measurements, we considered data from the TADs variables from the GQ and ambient ozone concentrations.

We investigated the distribution of O_3 personal exposure by study period and area. We investigated the association between personal exposure to O_3 and the potential determinants using linear mixed models. In order to account for the repeated measurements for each child during the 5 weeks we applied random effects models, incorporating a random intercept. Specifically, as covariates we used activity variables derived from the TADs ("Time spent indoors, at home", "Time spent outdoors", "Time spent in transportation" and "Time spent indoors, other than at home", each as continuous weekly averages in hours); the corresponding at-school outdoor O_3 ($\mu g/m^3$) measurements and the nearby fixed site O_3 concentrations. Furthermore, selected variables derived from the general questionnaire were examined as possible determinants: sex (girls vs boys), in house smoking (yes vs no), air condition use (yes vs no), heating using an open fireplace (yes vs no), duration of open windows (in hours), mode of transport to school (on foot vs by car or bus; by car or bus vs on foot), out-of-school indoor and outdoor activities in the afternoon (yes vs no), mode of transport to out-of-school indoor or outdoor activities, or other activities than mentioned before during weekends (as above).

We initially investigated the associations between personal exposure to O_3 and all predictor variables used alternatively in different models. For every mixed effect model marginal R squared ($\boldsymbol{R_M^2}$) values were derived to assess model fit (Nakagawa & Schielzeth 2013). The model with the highest $\boldsymbol{R_M^2}$ was regarded as the start model. To this start model all predictor variables that were statistically significant in the one-determinant models were added consecutively, using a supervised forward stepwise procedure. Only the predictor variables that remained statistically significant were included in the final model. In all models, we adjusted for the design area variables: a) study city (Thessaloniki/Athens), b) high vs low O_3 concentrations area and time period, to account for seasonality (using 4 dummy variables for the five weeks). All tests were two-sided at a significance level of 0.05.

Results

Table 1 shows the personal, at-school outdoor and ambient from fixed sites O_3 ($\mu g/m^3$) concentrations. All concentrations were significantly higher in the third period (April to June) compared to the other two study periods ($p<0.05$); higher in the suburbs (high O_3 area) compared to the center of the city (low O_3 area) ($p=0.001$); and higher in Athens than in Thessaloniki ($p<0.001$). Ozone personal measurements ranged from 1 to 25.4 $\mu g/m^3$ in the first period (October-December 2013), from 0.8 to 17.1 9 $\mu g/m^3$ in the second study period (February 2014) and from 1 to 41.9 $\mu g/m^3$ in the third period (April to June 2014), while they were significantly ($p<0.001$) lower compared to the outdoor measurements either at school or the fixed monitoring sites. As the distribution of the O_3 personal exposures deviated from normality, it was log-transformed when used as a dependent variable in the models.

Table 2 provides a description of the study population, by city and study area according to O_3 concentrations based on the school's location. Life-style and housing characteristics and time activity patterns are presented. Children residing in the two cities were similar according to age and sex (51.5% boys in Athens vs 49.4% in Thessaloniki and of the same age). In Athens, most children living in low O_3 areas went to school on foot, while children in suburbs usually went by car or bus.

Table 3 and Figure 2 present the summary statistics for daily time activity patterns as calculated from the TADs (hours) by study period, city and exposure area. Children spent on average 17 hours/day indoors at home and more time was spent outdoors during the third period (Figure 2). Children in high O_3 areas spent on average more time in transportation than those living in low O_3 areas. In Athens suburbs, children spent on average more time indoors in places other than at home compared to those in low exposed areas.

Table 4 shows the results of linear mixed models using the log transformed personal exposure to O_3 as the dependent variable. One-independent variable models denoted that the at-school outdoor O_3 measurements were strongly associated with the personal exposure to O_3. The fixed site ambient O_3 and PM_{10} concentrations were also a significant determinants of personal exposure. Regarding the TAD variables, the strongest association was with increased time spent in transportation (p=0.049) which was associated with increased O_3 personal exposure and at home (p=0.056) associated with decreased O_3 personal exposure. The only general questionnaire variable significantly associated with personal exposure to O_3 was increased duration of open windows.

Table 5 presents the mixed models effect estimates for potential determinants of O_3 personal exposure chosen after applying a supervised forward stepwise procedure. At-school outdoor and fixed monitoring site O_3 measurements (alternatively considered), duration of open windows, PM_{10} measurements from fixed sites and time spent in transportation were significantly associated with personal exposure to O_3. Specifically, for a half an hour more spent in transportation an average increase of 7% (95% CI: 0.3% , 14.6%) in personal exposure to O_3 is observed. For a 10 $\mu g/m^3$ increase in at-school outdoor O_3 concentrations and PM_{10} measurements a 20.9%

(95% CI: 13% , 28%) and 12.5% (95% CI: 4% , 22%) increase in personal exposure to O_3 is found, respectively. Finally, for one more hour/day with the windows open an average increase of 2% (95% CI: 0.1% , 3.7%) in personal exposure to O_3 is observed. We did not further adjust for ambient O_3 at fixed sites since the correlation between the at-school outdoor and measured from fixed sites O_3 was 0.73. The use of O_3 concentrations at fixed sites resulted in models with lower values of the marginal R squared.

Discussion

In a panel study in Greece, we measured school children's personal and at-school outdoor exposure to O_3 for 5-weeks during the academic year 2013-14. The present results indicate that ambient O_3 measurements from fixed sites and at-school outdoor concentrations are significant determinants of personal exposure to O_3, which although, is better determined by the latter. This is consistent with some of the previous findings, in which outdoor and ambient concentrations were found to be among the most important predictors of personal exposure to O_3 (Geyh et al., 1999; Liu et al., 1995; O'Neil et al., 2003; Ramirez-Aguilar et al., 2008; Xue et al., 2005). Other studies, however, conducted in the US, suggest that associations between ambient concentrations from fixed sites and personal exposure to O_3 exist only in the summer and are weak (Sarnat et al., 2005;Sarnat et al., 2006; Brown et al., 2009). The inconsistent conclusions seen in the various studies may reflect the differences in the geographic locations, life style (e.g. the use of air conditioning and more time spent indoors), the climatic conditions and the study designs.

Spending more time in transportation (TADs) was significantly associated with higher personal O_3 exposure even after adjusting for outdoor levels. These findings are also consistent with the results of similar studies conducted in children (Lee et al., 2004;

Ramirez-Aguilar et al., 2008; Xue et al., 2005) and adults (Liu et al., 1995), in which personal exposure to O_3 was determined by time activity information (i.e. time spent outdoors and time of the day children were outdoors). The same studies also found that housing characteristics (i.e. house fan usage, presence of a gas range in the house and distance between the residence and the fixed ambient monitoring stations); and lifestyle factors (i.e. having pets) are important predictors for personal exposure to O_3. Regarding housing factors, only the duration of open windows was significantly associated to personal exposure to O_3 in the present study.

Our study is based on a representative sample of school children that live in two major cities of Greece the population of which comprise about half of the Greek population. In addition, these cities provide an excellent opportunity to study O_3 effects as concentrations are high due to precursor pollutant emissions and climate conditions. The present study was conducted for a relatively long period of follow up and had a large sample of students. It obtained repeated measures of personal, at-school outdoor and ambient O_3 concentrations and time-activity information. This allowed us to fit alternate mixed models for investigating a variety of potential determinants of personal exposure to O_3. One limitation of our study is the difficulty of collecting data through the self-completion of TADs. However, exhausting data quality control procedures were followed and controls with manual inspections of the data and cross references from the field workers' progress diaries, that limited inaccurately reported data.

Based on our results a prediction model for estimating personal exposure to O_3 in children living in a Mediterranean climate can be implemented. Using our models personal exposure estimation could be applied in epidemiological studies in which the use of personal O_3 monitoring devices is not feasible. Furthermore, the validity of our model in different populations could be easily tested by providing personal monitors to a subsample of participants before generalizing to the whole sample under investigation.

In conclusion, we found geographical and temporal differences in personal O_3 exposures. Ozone personal measurements were significantly lower compared to the outdoor measurements. At-school outdoor level of O_3 was the major predictor of personal exposure to O_3. PM_{10} measurements from fixed sites, duration of open windows and time spent in transportation were also significantly associated with personal exposure to O_3. Our results support the use of outdoor and ambient measurements from fixed sites in epidemiological studies as a proxy of personal exposure to O_3, taking into account time-activity patterns and possibly calibration factors.

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Table 1. Descriptive statistics of personal exposure to ozone (O_3), at-school outdoor and fixed site measurements (μg/m^3), by study period, city and O_3 concentrations area.

	Athens		Thessaloniki	
Study period	**Low O_3 area**	**High O_3 area**	**Low O_3 area**	**High O_3 area**
October to December 2013				
Personal weekly O_3 concentration (μg/m^3)				
Samples (n)	60	109	28	49
Mean (SD)	6.1 (3.51)	8.2 (5.33)	2.0 (1.37)	2.1 (1.03)
Median (25th-75th)	5.7 (4.3-7.5)	7.3 (4.3-11.0)	1 (1-2.6)	1.8 (1.2-2.8)
Min-Max	1.2 - 19	1.2 - 25.4	1 - 6.2	1 - 4.9
At-school outdoor weekly O_3 concentration (μg/m^3)				
Mean (SD)	35.7 (5.25)	52.6 (12.62)	11.4 (2.98)	24.1 (10.49)
Median (25th-75th)	33.7 (32.4-42.2)	57.3 (42.3-60.1)	10.3 (10.3-13.4)	23.6 (16.4-24.3)
Min-Max	28.4 - 42.7	32.6 - 96.3	8.5 - 23.9	15.6 - 80.0
Fixed sites weekly average of O_3 concentration (μg/m^3)				
Mean (SD)	32.8 (11.45)	66.7 (15.13)	28.4 (10.98)	51.8 (19.37)
Median (25th-75th)	33.9 (21.0-42.7)	65.4 (53.6-70.9)	26.7 (18.0-34.2)	49.7 (40.9-77.6)
Min-Max	17.2 - 48.9	50.6 - 105.6	17.1 - 44.9	24.2 - 100.6
February 2014				
Personal weekly O_3 concentration (μg/m^3)				
Samples (n)	28	53	25	42
Mean (SD)	2.7 (2.24)	4.8 (3.89)	2.7 (1.72)	3.6 (1.67)
Median (25th-75th)	2.2 (0.8-3.6)	3.7 (2.6-5.2)	2.2 (1.7-3.1)	3.7 (2.6-4.4)
Min-Max	0.8 - 10.6	0.8 - 17.1	1.0 - 8.0	1.0 - 7.0
At-school outdoor weekly O_3 concentration (μg/m^3)				
Mean (SD)	33.7 (1.58)	48.1 (12.22)	22.1 (5.88)	27.1 (4.44)
Median (25th-75th)	33.6 (32.3-34.0)	48.9 (33.4-61.9)	20.5 (17.8-23.9)	25.1 (25.1-29.0)
Min-Max	28.4 - 38.7	32.8 - 63.1	17.8 - 51.2	24.5 - 56.0
Fixed sites weekly average of O_3 concentration (μg/m^3)				
Mean (SD)	39.7 (2.24)	75.5 (5.92)	37.9 (0.91)	50.4 (11.11)
Median (25th-75th)	39.3 (28.1-50.1)	75.0 (72.6-77.1)	38.0 (36.9-39.0)	55.6 (37.0 - 57.6)
Min-Max	17.2 - 50.3	51.4 - 85.3	36.9 - 39.0	37.0 - 69.4
April to June 2014				
Personal weekly O_3 concentration (μg/m^3)				
Samples (n)	55	90	38	73
Mean (SD)	13.2 (7.56)	17.6 (7.10)	7.7 (5.15)	9.8 (8.34)
Median (25th-75th)	13.2 (8.3-18.7)	17.3 (12.6-21.6)	6.2 (3.4 - 11.7)	6.9 (4.5 - 10.7)
Min-Max	1.2 - 33.8	3.1 - 41.8	1 - 21.7	1.2 - 41.9
At-school outdoor weekly O_3 concentration (μg/m^3)				

Mean (SD)	62.3 (7.93)	84.5 (10.37)	53.2 (9.60)	60.4 (9.30)
Median (25th-75th)	65.4 (60.5-66.9)	78.2 (76.4-90.4)	49.4 (44.6-62.8)	61.6 (56-61.8)
Min-Max	44.6 - 69.2	76 - 107	41.3 - 70	45.8 - 80
Fixed sites weekly average of O_3 concentration (µg/m^3)				
Mean (SD)	35.6 (26.40)	100.0 (5.91)	72.1 (3.04)	81.3 (12.16)
Median (25th-75th)	19.7 (10.4-67.3)	101.7(99.1-104.1)	72.7 (69.3-75.6)	83.1 (69.4-92.4)
Min-Max	7.1 - 73.6	88.9 - 106.9	69.1 - 76.3	66.1 - 100.6

Table 2. Characteristics of children participating in the RESPOZE panel study during the academic year 2013-14, by city and O_3 concentrations area.

	Athens		Thessaloniki	
	Low O_3 area (n=37)	**High O_3 area (n=60)**	**Low O_3 area (n=32)**	**High O_3 area (n=57)**
Boys (n, %)	22 (59.5)	28 (46.7)	14 (42.4)	30 (51.7)
Age (yrs; mean, (SD))	10.3 (0.3)	10.3 (0.3)	10.4 (0.4)	10.4 (0.3)
Father's Education (yrs; mean (SD))	14.0 (2.8)	15.2 (3.7)	15.3 (3.4)	14.1 (3.3)
In house cigarette smoking (yes; n, %)	14 (38.9)	14 (23.3)	7 (21.2)	13 (22.4)
Air condition (yes; n, %)	28 (75.7)	45 (75.0)	25 (75.8)	48 (82.8)
Open windows (hours/day; mean, (SD))	10.9 (3.37)	11.8 (3.64)	12.2 (3.42)	11.2 (4.13)
Transportation to school				
• On foot (n, %)	30 (81.1)	26 (43.3)	23 (69.7)	41 (71.9)
• By car/bus (n, %)	6 (16.2)	44 (73.3)	8 (24.2)	32 (55.2)

Table 3. Mean (standard deviation) of activity variables (time spent daily; hours) derived from the time activity diaries (TADs), by study period, city and O_3 concentrations area.

	Athens		Thessaloniki	
	Low O_3 area (n=37)	**High O_3 area (n=60)**	**Low O_3 area (n=32)**	**High O_3 area (n=57)**
Time spent indoors, at home (hours)				
October to December 2013	18 (2.5)	17 (1.8)	17 (1.9)	17 (1.6)
February 2014	17 (2.8)	17 (1.8)	17 (1.4)	17 (1.6)
April to June 2014	17 (2.2)	17 (1.9)	17 (1.4)	17 (2.1)
Time spent outdoors (hours)				
October to December 2013	0.9 (0.9)	0.9 (0.7)	1.4 (1.1)	1.3 (0.8)
February 2014	0.7 (0.9)	0.8 (0.8)	2.0 (0.9)	1.6 (0.9)
April to June 2014	1.1 (1.1)	1.4 (1.0)	1.8 (1.2)	1.6 (1.0)
Time spent in transportation (hours)				
October to December 2013	0.8 (0.6)	0.9 (0.3)	0.5 (0.5)	0.6 (0.3)
February 2014	0.7 (0.4)	0.9 (0.4)	0.7 (0.3)	0.8 (0.4)
April to June 2014	0.7 (0.3)	0.9 (0.4)	0.4 (0.3)	0.6 (0.4)
Time spent indoors, other than at home (hours)				
October to December 2013	4.3 (1.5)	5.3 (1.7)	5.4 (1.5)	5.0 (1.1)
February 2014	4.8 (1.3)	5.0 (1.4)	4.5 (1.1)	4.6 (1.2)
April to June 2014	4.6 (1.6)	4.9 (1.6)	4.9 (1.6)	4.7 (1.2)

Table 4. Mixed models estimates (coefficients (b) per fixed increment and 95% confidence intervals (CI)) for determinants of log transformed personal exposure to O_3 (μg/m^3) and percent change and 95% confidence intervals (CI) in personal exposure to O_3. Results from linear mixed models for determinants considered alternatively, adjusting for design area variables (study area: Thessaloniki vs Athens; O_3 concentration area: high vs low) and study week (4 dummy variables).

Independent variable	**One-independent variable models**			
TAD* variables (time spent; hours)	R_M^2	**b (95% C.I.)**	**% change (95% C.I.)**	**p-value**
Indoors, at home (per hour/day)	0.522	-0.023 (-0.047 , 0.001)	-2.3 (-4.6 , 0.1)	0.056
Outdoors (per hour/day)	0.520	0.042 (-0.013 , 0.097)	4.3 (-1.3 , 10.2)	0.137
In transportation (per half hour/day)	0.522	0.069 (0.000 , 0.137)	7.1 (0.0 , 14.7)	0.049
Indoors, other than at home (per hour/day)	0.519	0.011 (-0.023 , 0.046)	1.1 (-2.3 , 4.7)	0.516
Fixed outdoor pollutant measurements (μg/m^3)				
At-school outdoor (per 10 μg/m^3)	0.540	0.177 (0.115 , 0.239)	19.3 (12.2 , 27.0)	<0.001
Fixed monitoring site (per 10 μg/m^3)	0.525	0.044 (0.010 , 0.079)	4.5 (1.0 , 8.2)	0.012
PM_{10} measurements from fixed sites (per 10 μg/m^3) (Athens & Thessaloniki)	0.523	0.083 (0.004 , 0.163)	8.7 (0.4 , 17.7)	0.039
Other potential determinants from the GQ*				
Gender (girls vs boys)	0.519	0.036 (-0.096 , 0.168)	3.7 (-9.1 , 18.3)	0.592
In house cigarette smoking (yes vs no)	0.524	-0.069 (-0.220 , 0.081)	-6.7 (-19.8 , 8.5)	0.366
Air condition (yes vs no)	0.522	-0.128 (-0.282 , 0.026)	-12.0 (-24.6 , 2.6)	0.103
Open windows (per hour/day)	0.525	0.020 (0.002 , 0.037)	2.0 (0.2 , 3.8)	0.030
Transportation to school (on foot vs all others)	0.522	0.113 (-0.024 , 0.250)	11.9 (-2.4 , 28.4)	0.107
Transportation to school (by car/bus vs all others)	0.519	-0.117 (-0.260 , 0.026)	-11.0 (-22.9 , 2.6)	0.109

R_M^2: marginal R squared
*TAD: Time Activity Diary; GQ: General Questionnaire

Table 5. Mixed models estimates (coefficients (b) per fixed increment and 95% confidence intervals (CI)) for determinants of log transformed personal exposure to O_3 ($\mu g/m^3$) and percent change and 95% confidence intervals (CI) in personal exposure to O_3. Results from linear mixed models for determinants mutually adjusted a. considering the at-school outdoor weekly O_3 concentrations and b. the fixed monitoring sites weekly average of O_3 concentrations and adjusted for design area variables (study area: Thessaloniki vs Athens; O_3 concentration area: high vs low) and study week (4 dummy variables).

	Independent variables	R_M^2	**b (95% C.I.)**	**% change (95% C.I.)**	**p-value**
Model 1					
a.	At-school outdoor O_3 ($10\mu g/m^3$) +	0.546	0.175 (0.113,0.236)	19.1 (12.0 , 26.7)	<0.001
	Open windows (1 hour/day)		0.018 (0.001 , 0.036)	1.9 (0.1 , 3.7)	0.043
b.	Fixed monitoring site O_3 ($10\mu g/m^3$) +	0.531	0.044 (0.009 , 0.078)	4.5 (0.9 , 8.1)	0.014
	Open windows (1hour/day)		0.019 (0.001 , 0.037)	1.9 (0.1 , 3.7)	0.033
Model 2					
a.	At-school outdoor O_3 ($10\mu g/m^3$) +	0.551	0.187 (0.126 , 0.248)	20.6 (13.4 , 28.2)	<0.001
	Open windows (1 hour/day) +		0.019 (0.002 , 0.037)	2.0 (0.2 , 3.8)	0.028
	PM_{10} measurements ($10\mu g/m^3$)		0.120 (0.042 , 0.198)	12.8 (4.3 , 21.9)	0.002
b.	Fixed monitoring site O_3 ($10\mu g/m^3$) +	0.533	0.040 (0.005 , 0.074)	4.0 (0.5 , 7.7)	0.026
	Open windows (1hour/day) +		0.020 (0.002 , 0.037)	2.0 (0.2 , 3.8)	0.026
	PM_{10} measurements ($10\mu g/m^3$)		0.077 (-0.002 , 0.157)	8.0 (-0.2 , 17.0)	0.056
Model 3					
a.	At-school outdoor O_3 ($10\mu g/m^3$) +	0.552	0.186 (0.124 , 0.247)	20.9 (13.2 , 28.0)	<0.001
	Open windows (1hour/day) +		0.019 (0.001 , 0.036)	1.9 (0.1 , 3.7)	0.035
	PM_{10} measurements ($10\mu g/m^3$) +		0.118 (0.038 , 0.198)	12.5 (3.9 , 21.9)	0.004
	In transportation (time spent; half hour/day)		0.069 (0.003 , 0.136)	7.2 (0.3 , 14.6)	0.041
b.	Fixed monitoring site O_3($10\mu g/m^3$)+	0.535	0.042 (0.007 , 0.078)	4.3 (0.7 , 8.1)	0.019
	Open windows (1hour/day)+		0.019 (0.002 , 0.037)	1.9 (0.2 , 3.7)	0.032
	PM_{10} measurements ($10\mu g/m^3$)+		0.072 (-0.010 , 0.153)	7.4 (-1.0 , 16.6)	0.085
	In transportation (time spent; half hour/day)		0.147 (0.012 , 0.282)	7.6 (0.6 , 15.2)	0.033

R_M^2: marginal R squared